**AGENCY OF TRANSPORTATION** **OFFICE MEMORANDUM**

**To:** Kristin Higgins, P.E., Structures Project Manager
MLM

**From:** Marcy Meyers, Geotechnical Engineer, via Callie Ewald, P.E., Senior Geotechnical Engineer
CEE

**Date:** March 10th, 2014

**Subject:** Barnard ER BRF 0241(39) Wave Equation Analysis Review

The following summarizes our review of the wave equation analysis conducted for the piles proposed for the Barnard ER BRF 0241(39) project. We received a copy of the wave equation analysis provided to Paul Holloway of Miller Construction, Inc. that was conducted by Michael Deery of GZA GeoEnvironmental, Inc. (GZA) and Pile Driving & Equipment form prepared by the contractor. Mr. Deery performed wave equation analyses for the pile and hammer proposed for use at Abutment No. 1. The Delmag D16-32 single-acting diesel hammer was requested for analysis with a maximum rated energy of 40,198 ft-lbs. This hammer was evaluated for the pile-soil system for the Barnard ER BRF 0241(39) site only.

The characteristics of the proposed pile as well as the hammer and hammer cushion data were reviewed in the WEAP analysis to ensure the analysis was conducted per the contractors' submitted pile and driving equipment data form.

GZA modeled both a variable capacity analysis which develops a driving resistance based on the most efficient hammer stroke for all four fuel settings, as well as a constant capacity analysis or Inspector's Chart which develops a driving resistance based on a varied hammer stroke for the open fuel setting (fuel setting 4). All four variable capacity analyses assumed a triangular distribution of soil resistance and 80% capacity to be developed in end bearing. We are comfortable with the chosen analysis with respect to the subsurface information presented in the previous geotechnical reports.

Based on a review of the material submitted, we agree with the recommendations put forth by GZA in their report dated February 19th, 2014, which recommends a driving criterion of 11 blows per inch for three consecutive inches and a stroke of 8.5 feet while operating on fuel setting 3. At these blow counts, the stresses in the pile are expected to remain below 45 ksi per GZA's analysis. A saximeter is required to be on site to monitor the driving process at each substructure. We recommend using a refusal criterion as 10 blows per half inch with a minimum 9.0 foot ram stroke.

The 2011 VTrans Standard Specifications for Construction, Section 504.02(b), states the pile driving equipment must be capable of driving the pile to the required ultimate capacity at blow counts between 3 and 15 BPI. **Based upon this information and the WEAP analysis, the Delmag D16-32 hammer should be able to drive the steel HP 12x74 piles to the desired resistance and stay within the specifications.**

The serial number of the hammer should be recorded and kept in the pile driving records. Also, it is important to note that the thickness and condition of the prescribed aluminum and conbest cushion should be inspected prior to driving any piles. **If the thickness of the hammer cushion has decreased by 25%, then the cushion should be replaced, per Agency Specifications.** Generally, the best time to inspect the hammer cushion is when the hammer first arrives on the job, and is placed in the leads.

cc: CEE/Project File
MLM

**GZA**
**GeoEnvironmental, Inc.**

*Engineers and Scientists*

Reviewed by VTrans
3-10-2014

February 19, 2014
File No. 02.0171821.00-C, PC

Mr. Paul Holloway
Miller Construction, Inc.
P.O. Box 86
Windsor, Vermont 05089

249 Vanderbilt Avenue
Norwood
Massachusetts
02062
781-278-3700
FAX 781-278-5701
http://www.gza.com

Re: Wave Equation Analyses
Barnard ER BRF 0241(39) – Abutment 1
Barnard, Vermont

Dear Mr. Holloway:

At your request, GZA GeoEnvironmental, Inc. (GZA) has performed Wave Equation Analyses of Piles (WEAP) for the hammer-pile-soil system proposed on the above referenced project site. These analyses were performed in general accordance with the project specifications. A copy of the completed GRLWEAP outputs are attached and the WEAP inputs are summarized below:

- Hammer- The Delmag D16-32 single acting diesel hammer has a ram weight of 3,520 lbs. and a maximum rated stroke of 11.4 feet, yielding a rated energy of 40,198 ft-lbs. The helmet cushioning material is modeled as 2 inches of aluminum and conbest. The D16-32 is equipped with a ratchet style fuel pump with four settings which limit the ram stroke to 5.3 feet, 7.5 feet, 10.0 feet, and 11.4 feet (open) and yield rated energies of 18,646 ft-lbs, 26,400 ft-lbs, 35,200 ft-lbs., and 40,198 ft-lbs, respectively. The pile type detailed below is modeled with the Delmag D16-32 operating on each of the above fuel settings. No pile cushion material is required for the pile type detailed below.

- Pile - 50-foot long HP 12x74 Grade 50 steel piles are modeled. The cross-sectional area for this pile type is 21.8 square inches. The specified nominal axial resistance of 402 kips is based upon dividing the maximum factored axial pile load of 261.3 kips by a performance factor of 0.65. The maximum allowable driving stresses for Grade 50 steel is 45 ksi (i.e. $0.9f_y$).

- Soil - Based on the subsurface information provided and the anticipated driving conditions, the resistance profile is modeled as 80% end-bearing and 20% skin friction, triangularly distributed along the embedded pile length.

- Analysis Two analyses model the above hammer-pile-soil system:

  1. Variable capacity analysis which develops a driving resistance based on the most efficient hammer stroke. Note that the Delmag D16-32 is modeled operating on each of the four (4) fuel settings for completeness.

2. Constant capacity analysis (i.e., Inspector's Chart) which develops a driving resistance based on a varied hammer stroke.

- Results The results of these analyses are tabulated below:

Nominal Resistance: 402 kips

| Pile Hammer | Fuel Setting | Blow Count (bpi) | Ram Stroke (ft) | Compressive Stress (ksi) | Transfer Energy (kip-ft) |
|---|---|---|---|---|---|
| Delmag D30-32 | 1 | 21 bpi | 6.9 ft. | 25.4 ksi | 11.1 kip-ft |
| | 2 | 15 bpi | 7.6 ft. | 27.8 ksi | 13.1 kip-ft |
| | 3 | 11 bpi | 8.5 ft. | 30.3 ksi | 15.3 kip-ft |
| | Open (4) | 9 bpi | 9.5 ft. | 32.9 ksi | 17.8 kip-ft |

The results tabulated above indicate that the Delmag D16-32 open-end diesel hammer, operating on fuel setting 2, fuel setting 3, or fuel setting 4 can drive the specified HP12x74 Grade 50 steel piles to a nominal resistance of 402 kips without overstressing the pile section. Fuel setting 1 indicates a penetration resistance that exceeds the allowable Vermont Agency of Transportation (VAOT) specified blow count of 15 blows per inch.

Based on the above results and our experience with these type driving conditions, the preliminary recommended driving resistance is 11 blows per inch with the Delmag D16-32 operating on the fuel setting 3 (rated 10.0 foot ram stroke) and providing a ram stroke of approximately 8.5 feet. The maximum calculated driving stress of 30.3 ksi is within the allowable limits for Grade 50 steel. We recommend that this driving criterion be developed for a minimum of 3 consecutive inches. It is our understanding the driving criterion will be verified with the specified dynamic pile-testing program.

The project documents require that the specified HP12x74 steel piles achieve a minimum penetration of 20 feet (i.e. min. tip elevation +856.0) below the bottom of the pile cap. Our review of the contract boring logs indicate that the installed piles must penetrate an upper stratum of cobbles and weather rock and then penetrate five to ten feet into the lower stratum of weathered broken rock and cobbles to meet the minimum penetration criterion. Our experience with this type of driving condition is that the upper rock stratum may affect the pile alignment and the piles may not be able to develop the minimum penetration criterion if they develop bearing on competent rock in the underlying broken rock and cobble stratum.

If the pile driving system should demonstrate refusal conditions (i.e., sudden increase in ram stroke and penetration resistance), we recommend a refusal criteria of 10 blows per half-inch of pile penetration with the Delmag D16-32 providing a minimum 9.0 foot ram stroke.

If you have any questions or require additional information, please contact the undersigned.

Very truly yours,

GZA GEOENVIRONMENTAL, INC.

for Michael J. Deery
Geotechnical Engineer

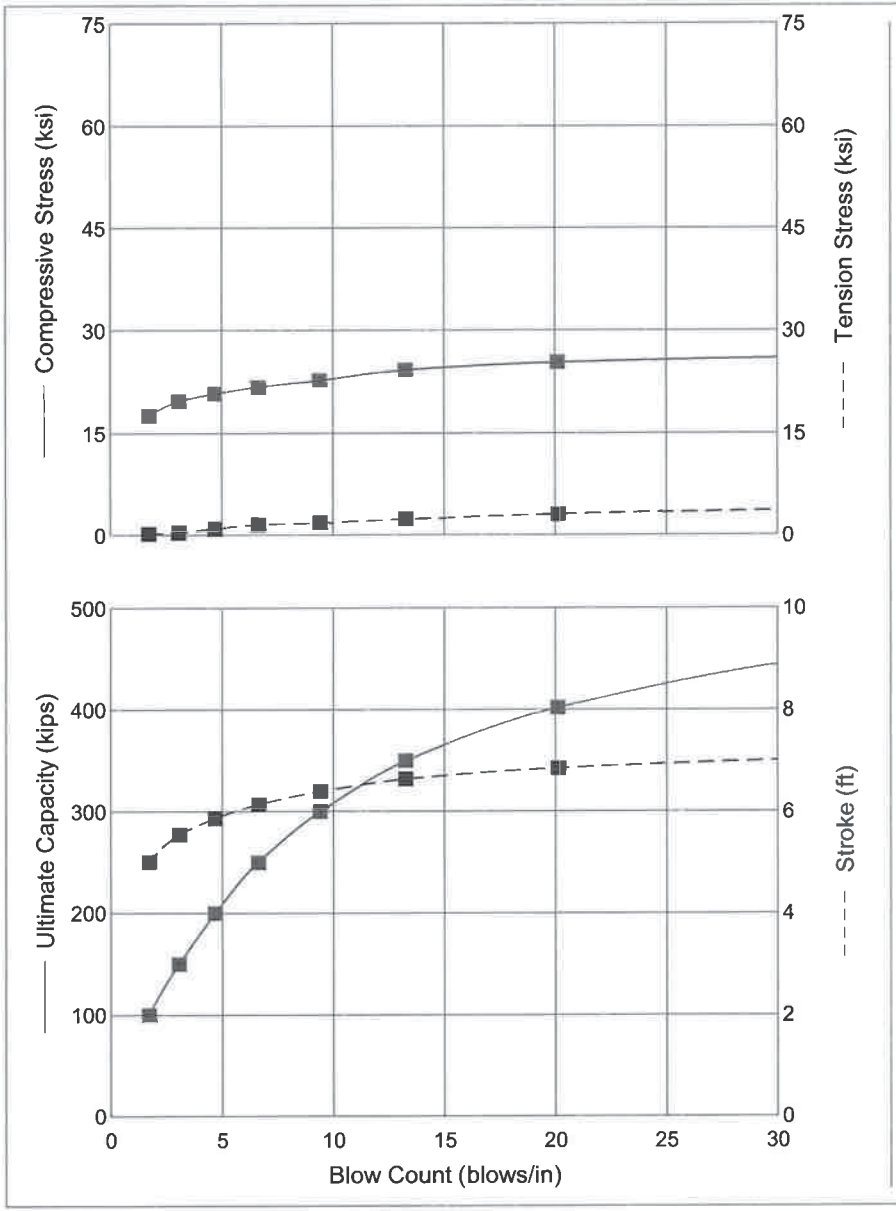
Bradford W. Roberts
Consultant / Reviewer

John E. Regan
Principal

Attachments: Wave Equation Analysis Results

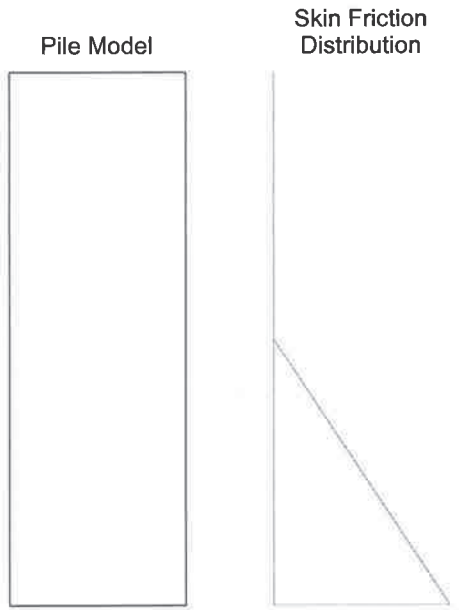
GZA GeoEnvironmental Inc.
Barnard D16-32 (FS 1) 50' HP12x74 VC

05-Feb-2014
GRLWEAP Version 2010




DELMAG D 16-32

| | | |
|---|---|---|
| Ram Weight | 3.52 | kips |
| Efficiency | 0.800 | |
| Pressure | 1039 (73%) | psi |
| Helmet Weight | 1.90 | kips |
| Hammer Cushion | 60155 | kips/in |
| COR of H.C. | 0.800 | |
| Skin Quake | 0.100 | in |
| Toe Quake | 0.100 | in |
| Skin Damping | 0.200 | sec/ft |
| Toe Damping | 0.150 | sec/ft |
| Pile Length | 50.00 | ft |
| Pile Penetration | 25.00 | ft |
| Pile Top Area | 21.80 | in2 |



Reviewed by VTrans
3-10-2014

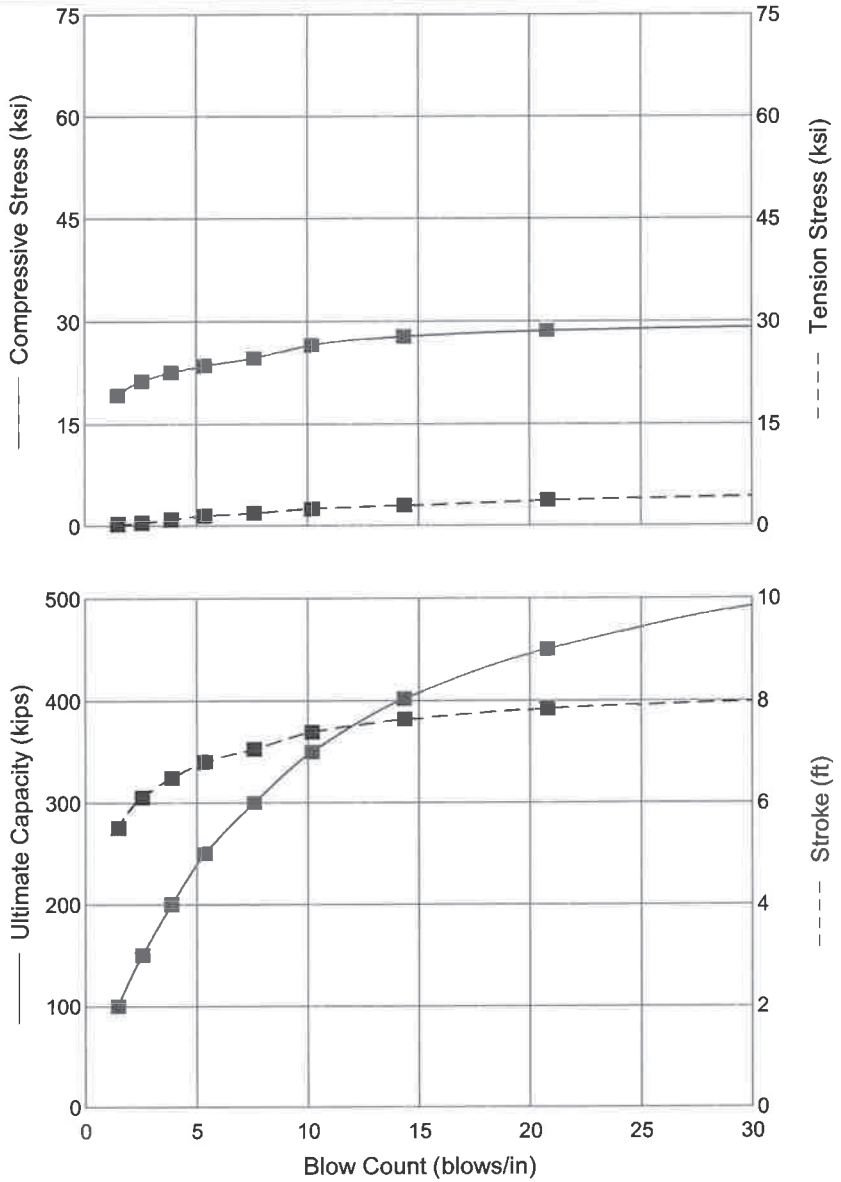
GZA GeoEnvironmental Inc.
Barnard D16-32 (FS 1) 50' HP12x74 VC

05-Feb-2014
GRLWEAP Version 2010

| Ultimate Capacity kips | Maximum Compression Stress ksi | Maximum Tension Stress ksi | Blow Count blows/in | Stroke ft | Energy kips-ft |
|---|---|---|---|---|---|
| 100.0 | 17.50 | 0.23 | 1.7 | 5.01 | 9.42 |
| 150.0 | 19.60 | 0.36 | 3.1 | 5.55 | 9.31 |
| 200.0 | 20.75 | 0.95 | 4.7 | 5.87 | 9.37 |
| 250.0 | 21.69 | 1.51 | 6.6 | 6.14 | 9.73 |
| 300.0 | 22.70 | 1.77 | 9.4 | 6.40 | 10.22 |
| 350.0 | 24.23 | 2.31 | 13.3 | 6.64 | 10.70 |
| 402.0 | 25.36 | 3.04 | 20.1 | 6.85 | 11.12 |
| 450.0 | 26.06 | 3.78 | 31.9 | 7.03 | 11.49 |
| 500.0 | 26.61 | 4.47 | 59.4 | 7.19 | 11.79 |
| 600.0 | 26.84 | 5.56 | 9999.0 | 7.30 | 11.95 |

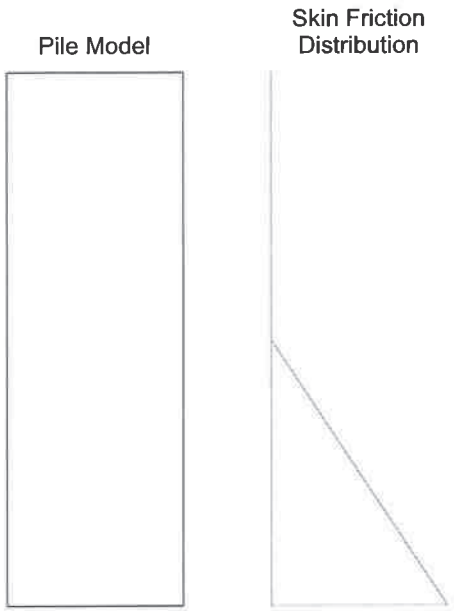
GZA GeoEnvironmental Inc.
Barnard D16-32 (FS 2) 50' HP12x74 VC

05-Feb-2014
GRLWEAP Version 2010




DELMAG D 16-32

| | | |
|---|---|---|
| Ram Weight | 3.52 | kips |
| Efficiency | 0.800 | |
| Pressure | 1154 (81%) | psi |
| Helmet Weight | 1.90 | kips |
| Hammer Cushion | 60155 | kips/in |
| COR of H.C. | 0.800 | |
| Skin Quake | 0.100 | in |
| Toe Quake | 0.100 | in |
| Skin Damping | 0.200 | sec/ft |
| Toe Damping | 0.150 | sec/ft |
| Pile Length | 50.00 | ft |
| Pile Penetration | 25.00 | ft |
| Pile Top Area | 21.80 | in2 |



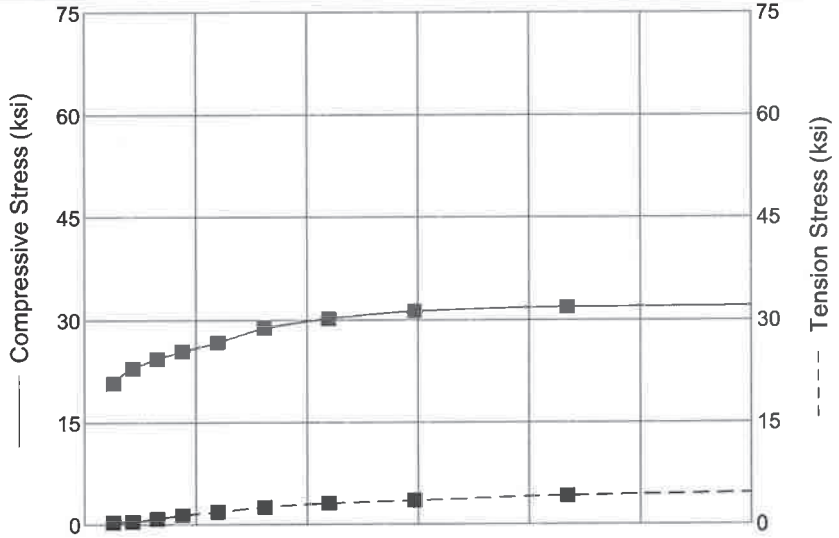
Reviewed by VTrans
3-10-2014

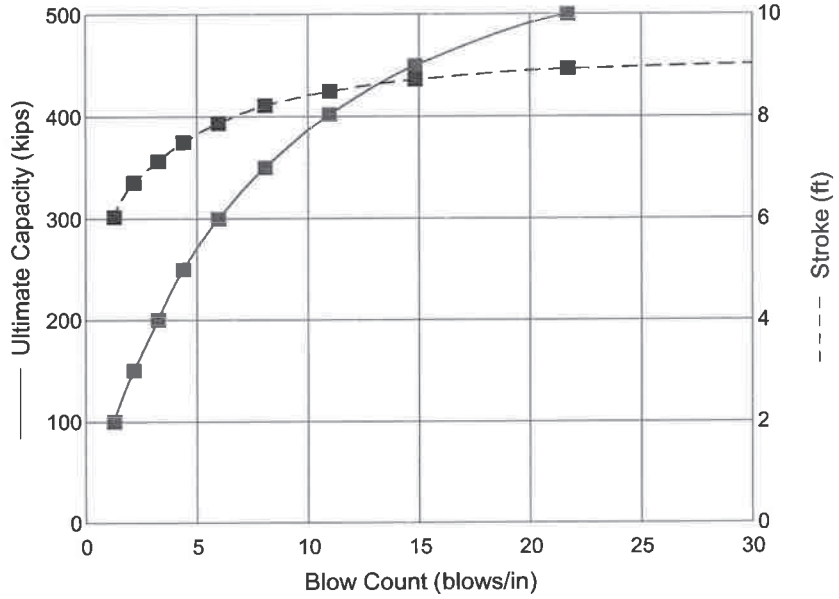
GZA GeoEnvironmental Inc. 05-Feb-2014
Barnard D16-32 (FS 2) 50' HP12x74 VC GRLWEAP Version 2010

| Ultimate Capacity kips | Maximum Compression Stress ksi | Maximum Tension Stress ksi | Blow Count blows/in | Stroke ft | Energy kips-ft |
|---|---|---|---|---|---|
| 100.0 | 19.13 | 0.28 | 1.5 | 5.50 | 11.43 |
| 150.0 | 21.26 | 0.44 | 2.6 | 6.11 | 11.15 |
| 200.0 | 22.50 | 0.93 | 3.9 | 6.48 | 11.18 |
| 250.0 | 23.52 | 1.46 | 5.4 | 6.80 | 11.52 |
| 300.0 | 24.61 | 1.85 | 7.6 | 7.06 | 11.89 |
| 350.0 | 26.52 | 2.46 | 10.2 | 7.39 | 12.60 |
| 402.0 | 27.79 | 2.95 | 14.3 | 7.63 | 13.10 |
| 450.0 | 28.62 | 3.67 | 20.8 | 7.84 | 13.50 |
| 500.0 | 29.19 | 4.43 | 33.5 | 8.01 | 13.85 |
| 600.0 | 29.66 | 5.71 | 183.8 | 8.22 | 14.20 |

GZA GeoEnvironmental Inc.
Barnard D16-32 (FS 3) 50' HP12x74 VC

05-Feb-2014
GRLWEAP Version 2010

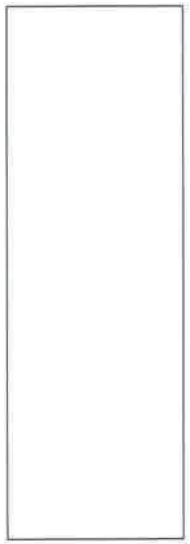



DELMAG D 16-32

| | | |
|---|---|---|
| Ram Weight | 3.52 | kips |
| Efficiency | 0.800 | |
| Pressure | 1283 (90%) | psi |
| Helmet Weight | 1.90 | kips |
| Hammer Cushion | 60155 | kips/in |
| COR of H.C. | 0.800 | |
| Skin Quake | 0.100 | in |
| Toe Quake | 0.100 | in |
| Skin Damping | 0.200 | sec/ft |
| Toe Damping | 0.150 | sec/ft |
| Pile Length | 50.00 | ft |
| Pile Penetration | 25.00 | ft |
| Pile Top Area | 21.80 | in2 |

Pile Model



Skin Friction Distribution

Res. Shaft = 20 %
(Proportional)

Reviewed by VTrans
3-10-2014

Reviewed by VTrans
3-10-2014

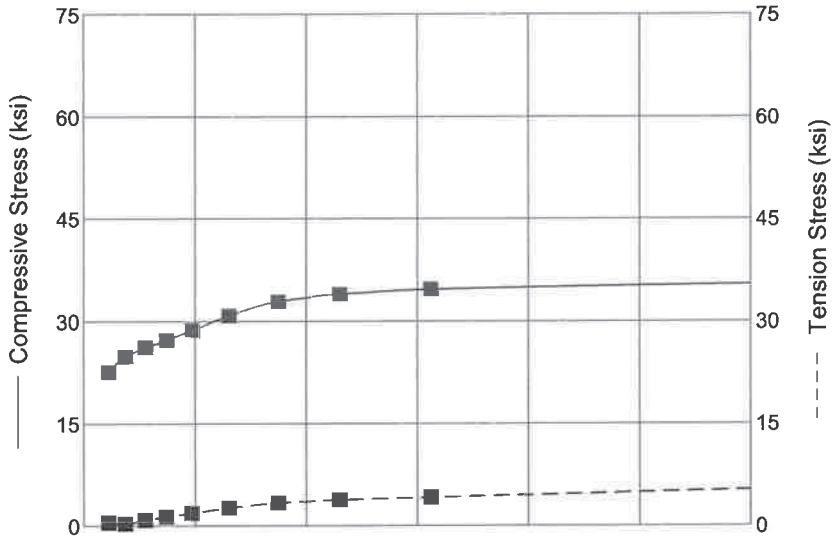
GZA GeoEnvironmental Inc.
Barnard D16-32 (FS 3) 50' HP12x74 VC

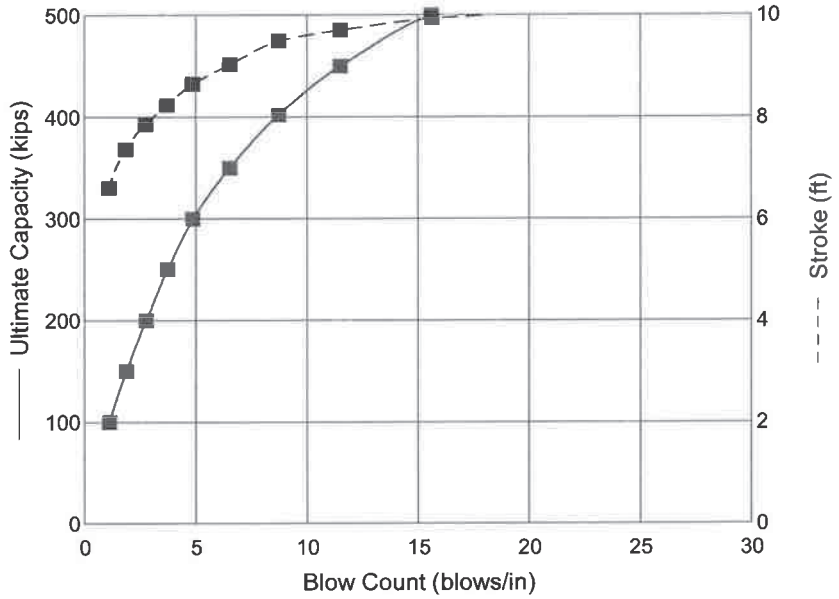
05-Feb-2014
GRLWEAP Version 2010

| Ultimate Capacity kips | Maximum Compression Stress ksi | Maximum Tension Stress ksi | Blow Count blows/in | Stroke ft | Energy kips-ft |
|---|---|---|---|---|---|
| 100.0 | 20.78 | 0.39 | 1.3 | 6.04 | 13.72 |
| 150.0 | 22.94 | 0.45 | 2.2 | 6.71 | 13.23 |
| 200.0 | 24.31 | 0.91 | 3.3 | 7.13 | 13.13 |
| 250.0 | 25.40 | 1.41 | 4.4 | 7.50 | 13.48 |
| 300.0 | 26.76 | 1.91 | 6.0 | 7.87 | 14.00 |
| 350.0 | 28.82 | 2.63 | 8.1 | 8.22 | 14.76 |
| 402.0 | 30.25 | 3.16 | 11.0 | 8.50 | 15.31 |
| 450.0 | 31.32 | 3.57 | 14.8 | 8.73 | 15.80 |
| 500.0 | 31.94 | 4.29 | 21.7 | 8.94 | 16.16 |
| 600.0 | 32.68 | 5.73 | 61.7 | 9.27 | 16.82 |

GZA GeoEnvironmental Inc.
Barnard D16-32 (FS 4) 50' HP12x74 VC

05-Feb-2014
GRLWEAP Version 2010

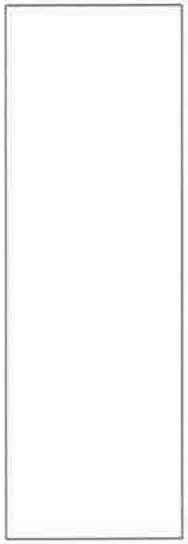



DELMAG D 16-32

| | | |
|---|---|---|
| Ram Weight | 3.52 | kips |
| Efficiency | 0.800 | |
| Pressure | 1425 (100%) | psi |
| Helmet Weight | 1.90 | kips |
| Hammer Cushion | 60155 | kips/in |
| COR of H.C. | 0.800 | |
| Skin Quake | 0.100 | in |
| Toe Quake | 0.100 | in |
| Skin Damping | 0.200 | sec/ft |
| Toe Damping | 0.150 | sec/ft |
| Pile Length | 50.00 | ft |
| Pile Penetration | 25.00 | ft |
| Pile Top Area | 21.80 | in2 |

Pile Model



Skin Friction Distribution

Res. Shaft = 20 %
(Proportional)

Reviewed by VTrans
3-10-2014

Reviewed by VTrans
3-10-2014

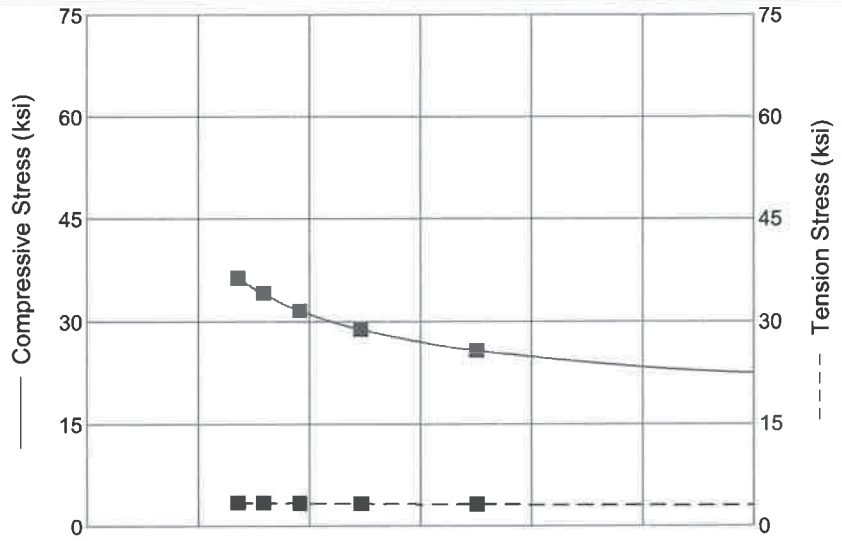
GZA GeoEnvironmental Inc.
Barnard D16-32 (FS 4) 50' HP12x74 VC

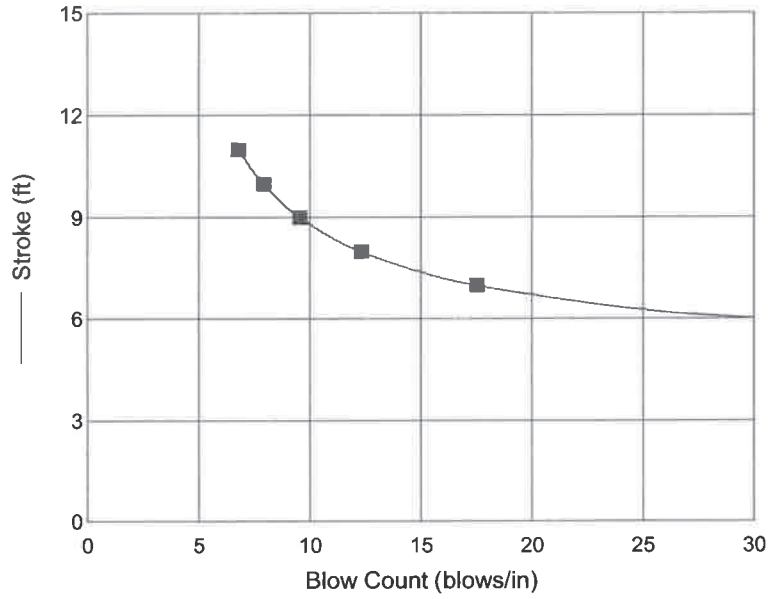
05-Feb-2014
GRLWEAP Version 2010

| Ultimate Capacity kips | Maximum Compression Stress ksi | Maximum Tension Stress ksi | Blow Count blows/in | Stroke ft | Energy kips-ft |
|---|---|---|---|---|---|
| 100.0 | 22.43 | 0.53 | 1.1 | 6.61 | 16.16 |
| 150.0 | 24.75 | 0.36 | 1.9 | 7.37 | 15.55 |
| 200.0 | 26.11 | 0.89 | 2.8 | 7.86 | 15.36 |
| 250.0 | 27.22 | 1.37 | 3.7 | 8.24 | 15.58 |
| 300.0 | 28.74 | 1.89 | 4.9 | 8.65 | 16.10 |
| 350.0 | 30.84 | 2.65 | 6.5 | 9.03 | 16.84 |
| 402.0 | 32.90 | 3.38 | 8.7 | 9.49 | 17.81 |
| 450.0 | 33.97 | 3.80 | 11.5 | 9.70 | 18.22 |
| 500.0 | 34.71 | 4.17 | 15.6 | 9.93 | 18.70 |
| 600.0 | 35.63 | 5.68 | 35.0 | 10.34 | 19.54 |

GZA GeoEnvironmental Inc.
Barnard D16-32 50' HP12x74 CC

06-Feb-2014
GRLWEAP Version 2010




DELMAG D 16-32

| | | |
|---|---|---|
| Capacity | 402.0 | kips |
| Ram Weight | 3.52 | kips |
| Efficiency | 0.800 | |
| Pressure | 1425 (100%) | psi |
| Helmet Weight | 1.90 | kips |
| Hammer Cushion | 60155 | kips/in |
| COR of H.C. | 0.800 | |
| Skin Quake | 0.100 | in |
| Toe Quake | 0.100 | in |
| Skin Damping | 0.200 | sec/ft |
| Toe Damping | 0.150 | sec/ft |
| Pile Length | 50.00 | ft |
| Pile Penetration | 25.00 | ft |
| Pile Top Area | 21.80 | in2 |

Pile Model

Skin Friction Distribution

Res. Shaft = 20 %
(Proportional)

Reviewed by VTrans
3-10-2014

GZA GeoEnvironmental Inc.
Barnard D16-32 50' HP12x74 CC

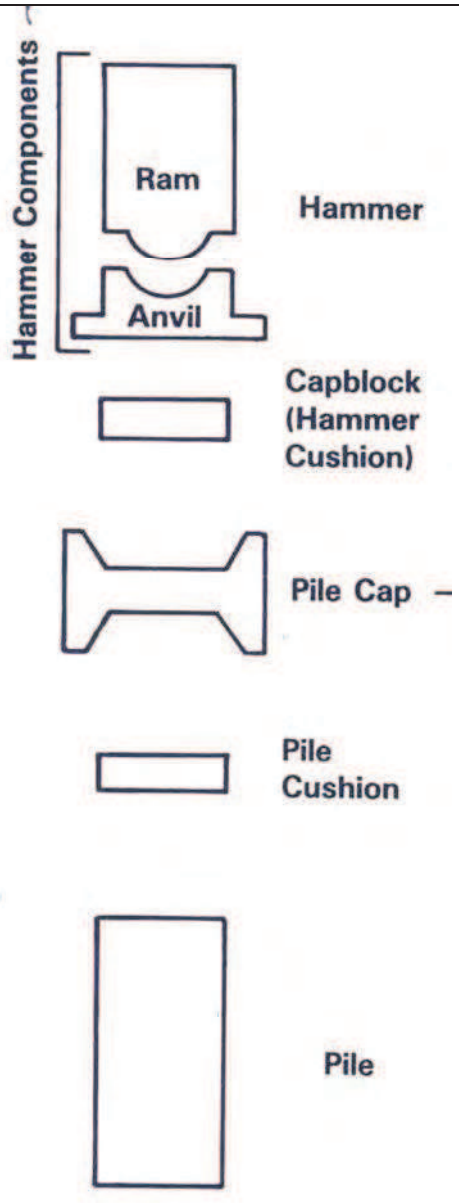
06-Feb-2014
GRLWEAP Version 2010

| Ultimate Capacity kips | Maximum Compression Stress ksi | Maximum Tension Stress ksi | Blow Count blows/in | Stroke ft | Energy kips-ft |
|---|---|---|---|---|---|
| 402.0 | 12.02 | 1.52 | 9999.0 | 3.00 | 2.97 |
| 402.0 | 15.20 | 2.47 | 9999.0 | 4.00 | 5.38 |
| 402.0 | 18.66 | 2.98 | 150.7 | 5.00 | 7.72 |
| 402.0 | 22.42 | 3.11 | 31.1 | 6.00 | 10.02 |
| 402.0 | 25.81 | 3.19 | 17.5 | 7.00 | 12.21 |
| 402.0 | 28.90 | 3.27 | 12.3 | 8.00 | 14.47 |
| 402.0 | 31.65 | 3.36 | 9.6 | 9.00 | 16.77 |
| 402.0 | 34.19 | 3.40 | 7.9 | 10.00 | 19.00 |
| 402.0 | 36.43 | 3.39 | 6.8 | 11.00 | 21.19 |

# Pile and Driving Equipment Data Form

**Project Name:** Barnard
**Project No.:** ER BRF 0241 (39)
**Route No.:** VT 12

**Structure Name:** Bridge 25 Crossing Locust Creek
**Structure No:** Bridge 25
**Pile Driving Contractor:** Miller Construction, Inc.
**Foreperson:** Ray Estey




**Manufacturer:** Delmag
**Type:** Diesel - Open End
**Rated Energy (kip-ft):** 39.2
**Length of Stroke (ft):** 11.15
**Model:** D16-32
**Serial No:** 408

**Modifications:** N/A

**Material:** Alum. and Conbest
**Thickness (in):** 2 **Area ($in^2$):** 227
**Modulus of Elasticity – E (ksi):** 530
**Coefficient of Restitution-e:** 0.8

**Also named:**
**Helmet**
**Bonnet**
**Anvil Block**
**Drivehead**

**Weight (lbs):** 1900

**Cushion material:** N/A
**Thickness (in):** N/A **Area ($in^2$):** N/A
**Modulus of Elasticity – E (ksi):** N/A
**Coefficient of restitution – e:** N/A

**Pile Type & Size:** HP 12 X 74
**Length (in Leads) (ft):** 40 - 50
**Weight (lb/ft):** 74
**Wall thickness (in):** N/A
**Taper:** N/A
**Cross Sectional Area ($in^2$):** 21.8
**Ultimate Axial Pile Capacity (kips):** 402
**Steel Yield Strength (ksi):** 50
**Description of Splice:** N/A
**Tip Treatment Description:** Hard Bite Point

**Distribution- One copy each to:**

- ☐ **State Structures Engineer**
- ☐ **State Soils & Foundations Engineer**
- ☐ **Resident Engineer:**

**NOTE: If mandrel is used to drive the pile, please attach separate manufacturer's detail sheet(s), including weight and dimensions.**

**Submitted by:** Paul J. Holloway
**Title:** Project Manager

**Date:** 11/18/13